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LOW-COST SOLAR-ARRAY PROJECT
Cell and Module Formation Research Area

PROCESS RESEARCH OF NON-CZ SILICON MATERIAL

QUARTERLY REPORT NO. 2
June 1, 1982 to August 31, 1982

Contract No. 955909

The JPL Low-Cost Silicon Array Project is sponsored by the U. S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE.

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I. CONTRACT GOALS AND OBJECTIVES

The primary objective of this contract is to investigate high-risk, high-payoff research areas associated with the Westinghouse process for producing photovoltaic modules using non-CZ sheet material. All investigations are being performed using dendritic web silicon, but all processes under study are directly applicable to other ribbon forms of sheet material. The contract is separated into the following tasks.

A. Liquid Junction Technical Feasibility Study

The objective of this task is to determine the technical feasibility of forming front and back junctions in non-CZ silicon using liquid dopant techniques. Numerous commercially available liquid phosphorus and boron dopant solutions will be investigated. Temperature-time profiles to achieve N^+ and P^+ sheet resistivities of 60 ±10 and 40 ±10 ohms per square centimeter respectively will be established. A study of the optimal method of liquid dopant application will be performed.

B. Liquid Diffusion Mask Feasibility Study

The objective of this task is to determine the technical feasibility of forming a liquid applied diffusion mask to replace the more costly chemical vapor deposited SiO_2 diffusion mask. Parameters to be investigated will include chemical identification of liquid applied diffusion masks, temperature-time profiles of baking liquid masks, film thickness relationship with masking capabilities, identification of etching solutions, process parameters for post-diffusion removal of masks, and methods of liquid mask application.

C. AR, PR Meniscus Coating Application Studies

The objective of this task is to determine the technical feasibility of applying liquid antireflective (AR) and photoresist (PR) solutions using meniscus coating equipment. Film thickness relationships with antireflective capabilities (AR) and masking capabilities (PR) will be investigated, and temperature-time profiles of baking liquid applied solutions for efficient etching techniques will be studied.

D. Ion Implantation Compatibility/Feasibility Study

In this task, the feasibility of producing uniform high efficiency solar cells from non-CZ silicon using ion implantation junction formation techniques will be established. This task will build upon existing information on ion implantation of non-CZ material gleaned on other programs and will include:

- An investigation of process variations between processing ion implanted cells and processing gaseous duffused cells using a standard gaseous diffusion process as a baseline;

- Comparison and evaluation of cell efficiencies of ion implanted cells with gaseous diffused cells using a standard gaseous diffusion process as a baseline; and an

- Evaluation of ion implantation parameters such as ion species, energy and dose for front and back junctions, ion implantation angle, annealing method, annealing time and temperature, surface treatment of input non-CZ material, and input non-CZ characteristics including resistivity.

E. Cost Analyses

In this task, SAMICS methodology will be used to quantify production cost improvements associated with process improvements under investigation.

II. SUMMARY

This report describes work performed on JPL Contract No. 955909, "Process Research of Dendritic Web Silicon," during the quarterly period running from June 1, 1982, to August 31, 1982. Technical work in this time period was focused on investigations of liquid diffusion masks and liquid applied dopants to replace the CVD Silox masking and gaseous diffusion operations specified for forming junctions in the Westinghouse baseline process sequence for producing solar cells from dendritic web silicon.

Extensive experiments conducted during this reporting period allowed direct comparisons of the baseline diffusion masking and drive processes with those involving direct liquid applications to the dendritic web silicon strips. In these experiments, attempts were made to control the number of variables by subjecting dendritic web strips cut from a single web crystal to both types of operations. Data generated have reinforced earlier conclusions that efficiency levels at least as high as those achieved with the baseline back junction formation process can be achieved using liquid diffusion masks and liquid dopants. The use of the liquid processes will improve the cost effectiveness of the Westinghouse process sequence by reducing chemical and equipment costs, simplifying procedures and controls required for the operations, and eliminating several cleaning steps.

It is worthy to note that contract funds are being used to define, evaluate, and report results on experiments discussed in this report; but all technician and material costs are being borne by Westinghouse.

In addition, the deliveries of dendritic web sheet material and solar cells specified by the current contract were made as scheduled. Also, a Summary Technical Report covering work on the MEPSDU contract from its initiation on November 26, 1980, through February 10, 1982, was prepared and distributed (Westinghouse TME 3149).

III. TECHNICAL PROGRESS

A. General

Technical work during the past quarter was focused on the first two tasks discussed in Section I of this report: liquid junction and liquid diffusion mask feasibility studies. Investigations on these two tasks are being coordinated with one another in matrix fashion, and results of experiments conducted to date are combined.

The Westinghouse baseline process for fabricating solar cells from dendritic web silicon includes the gaseous diffusion of boron and phosphorus to form the P^+P and N^+P junctions respectively in the N^+PP^+ junction structure. This diffusion process has demonstrated high efficiency cells but requires relatively expensive capital equipment (quartz tube diffusion furnaces) and a multi-step processing sequence. The two diffusion processes are conducted separately, and each is preceded with a chemical vapor deposition (CVD) of an SiO_2 (Silox) mask to allow diffusion in only one surface of the web (front or back) at a time.

The use of liquid dopants as an alternate to gaseous diffusion would reduce costs by reducing chemical and equipment costs, incorporating less involved procedures and simplified controls, and by eliminating several cleaning steps. The use of a liquid precursor to replace the CVD Silox mask would eliminate several clean-up steps associated with the baseline process sequence.

Experiments completed to date indicate that the only mechanism for applying liquid phosphorus to dendritic web with the uniformity required is through the use of a meniscus coating device. A coater, "CAVEX" developed by Integrated Technologies, has been placed on order (using Westinghouse capital funds) and is scheduled for delivery in the final quarter of this year. Liquid dopant experiments during the past quarter were restricted to the liquid boron and liquid SiO_2 solutions which can be readily and satisfactorily applied manually using a sponge squeegee.

B. Initial Experiments and Results

In order to evaluate liquid SiO_2 as a diffusion mask, detailed experiments were run to evaluate liquid SiO_2, baseline CVD-SiO_2, liquid boron, and BBr_3 in various combinations. The matrix used in one such experiment was as follows:

Liq SiO_2 Liq B	Liq SiO_2 BBr_3
Std SiO_2 Liq B	Std SiO_2 BBr_3

The overall results are summarized in Table 1, and comparisons of cells produced from a single web crystal are presented in Table 2. The results indicated that standard CVD Silox with liquid boron yields the highest efficiencies, but in this initial experiment there were some difficulties encountered removing the liquid SiO_2 layer after boron diffusion. Therefore, the results are suspect due to these application and removal problems. Another similar experiment was then performed using standard CVD Silox and two different liquid SiO_2 solutions to resolve the diffusion mask issue. The two liquid SiO_2 solutions were designated 700A* and 700B*, with the main difference in the viscosity of the solution. One run of 24 pieces of web strips was chosen for this experiment: 8 pieces were coated with CVD SiO_2, 8 pieces were coated with liquid SiO_2 700A, and 8 pieces were coated with liquid SiO_2 700B solution. Liquid boron dopant solution was used on all the pieces to produce the P^+ back surface. Results of this run are summarized in Table 3. It is seen in using the two SiO_2 solutions that there is no significant difference in the cell efficiencies. Since 700B is a thicker solution, it is more difficult to strip after diffusion. Based on these observations, it was decided that later verification runs would be made using the SiO_2 700A solution. However, it should be noted that this experiment established that the SiO_2 700B solution can also be used quite effectively as a diffusion mask.

*Filmtronics Corporation designations

TABLE 1

EFFICIENCIES MEASURED ON CELLS PROCESSED IN STANDARD SILOX/LIQUID SiO_2/STANDARD (GASEOUS) BBr_3/LIQUID BORON MATRIX EXPERIMENT

	Efficiency (pct); Measured with AR Coating			
Cell No.	Standard Silox/ Standard Boron	Liquid SiO_2/ Standard Boron	Standard Silox/ Liquid Boron	Liquid SiO_2/ Liquid Boron
1	12.19	12.29	13.52	12.29
2	12.34	12.24	14.23	12.39
3	10.81	11.83	11.38	8.41
4	10.71	11.83	10.26	7.95
5	11.27	7.65	12.81	12.04
6	12.50	7.34	12.35	12.04
7	12.60	12.34	12.70	10.96
8	12.29	12.55	13.72	11.42
9	12.60	11.27	14.28	12.34
10	12.70	12.39	14.85	12.39
11	12.85	11.78	15.56	10.86
12	12.60	11.88		11.17
13	13.82	11.98		11.53
14	14.03	8.57		11.68
15				10.96
16				12.14
17				13.01
18				13.06
Average	12.38 ±0.92	11.04 ±1.74	13.24 ±1.48	11.48 ±1.33

TABLE 2

COMPARISONS OF EFFICIENCIES OF CELLS PRODUCED FROM A SINGLE WEB CRYSTAL PRODUCED USING VARIOUS DIFFUSION DRIVE AND MASK PROCESS

1. Standard Silox Diffusion Mask

Crystal No.	Diffusion Drive	Cell No.	Cell Efficiency (%)
4-122-18	Liquid Boron	6A	11.38
4-122-18	Liquid Boron	6B	10.26
4-122-18	BBr_3	7A	12.50
4-122-18	BBr_3	7B	12.60
4-122-18	BBr_3	7C	12.29
4-122-16	Liquid Boron	11A	12.81
4-122-16	Liquid Boron	11B	12.35
4-122-16	Liquid Boron	11C	12.70
4-122-16	BBr_3	10A	12.6
1-157-1	Liquid Boron	15A	14.28
1-157-1	Liquid Boron	15B	14.85
1-157-1	Liquid Boron	15C	15.56
1-157-1	BBr_3	16A	13.82
1-157-1	BBr_3	16B	14.03

2. Liquid SiO_2 Diffusion Mask

Crystal No.	Diffusion Drive	Cell No.	Cell Efficiency (%)
4-122-13	Liquid Boron	54A	12.34
4-122-13	Liquid Boron	54B	12.39
4-122-13	BBr_3	55AX	12.29
4-122-13	BBr_3	55BX	12.24
1-156-23	Liquid Boron	66A	11.68
1-156-23	Liquid Boron	66B	10.96
1-156-23	BBr_3	65AX	12.34
1-156-23	BBr_3	65BX	12.55
7-131-3	Liquid Boron	68A	12.14
7-131-3	Liquid Boron	68B	13.01
7-131-3	Liquid Boron	68C	13.06
7-131-3	BBr_3	69AX	11.27
7-131-3	BBr_3	69BX	12.55
7-131-3	BBr_3	69CX	12.39

TABLE 3

CVD SILOX - LIQUID SIO_2
DIFFUSION MASK COMPARISON EXPERIMENT

- Total Cells

	CVD Silox	Liquid SiO_2 700A*	Liquid SiO_2 700B*
No. of Cells	15	14	19
Average Efficiency	12.18%	11.99%	12.29%
Maximum Efficiency	13.0%	13.87%	14.74%
Minimum Efficiency	11.68%	11.12%	11.27%

- Direct Comparison of Efficiencies of Cells from Same Web Crystal or Furnace Run

Run #1	12.13%	11.33%	11.32%
Run #2	12.34%	12.59%	12.13%

NOTE: Liquid boron diffusion process used on all cells.

*Filmtronics Corporation designations.

In addition to the liquid SiO_2 mask, a number of cell processing runs were made using both the standard baseline CVD SiO_2 (Silox) - gaseous BBr_3 process and the liquid SiO_2 - liquid boron process. The procedure followed on these runs is outlined in Table 4. Results of three such paired experiments are summarized in Table 5. Detailed analysis of this data shows that there is no significant difference in average efficiencies in the two processes. Direct comparison of cells produced from the same web crystals does show a slight edge for the liquid process. However, since the data base is extremely small, this efficiency variation is not considered significant.

Based on the results of this experiment, additional experiments were designed to make a direct comparison of BBr_3 versus liquid boron using liquid SiO_2 as a diffusion mask in both cases. The procedure followed on these process runs is outlined in Table 6. Results of a typical run are summarized in Table 7. Detailed analysis of this data shows that there is no significant difference in average efficiencies in the two types of processes. Based on these results, it has been concluded that the liquid SiO_2 - liquid boron process can be a direct replacement for the CVD SiO_2 - BBr_3 diffusion process while maintaining the high cell efficiencies observed with the baseline process sequence.

C. Verification Runs and Results

Plans were then made to verify the liquid SiO_2 - liquid boron process during a one week period of standard operation on the Westinghouse pre-pilot production line. During a one week period in August, all cell processing runs made on the Westinghouse pre-pilot facility were made using a liquid boron diffusant source to prepare the P^+P junction and a liquid SiO_2 diffusion mask during both the boron and phosphorus diffusions. The purpose of these runs was: (1) to verify that this technique is suitable for diffusing P^+P junctions and for producing high efficiency solar cells, and (2) to increase the data base as required to statistically quantify any improvements with this technique as opposed to the baseline gaseous diffusion process. The process sequence and materials used in this one week processing experiment are shown in Table 8. During this test period, a B201ET boron source and an SiO_2 - 700A mask source, both from Filmtronics Company in Butler, PA, were used. Twenty-one standard

TABLE 4

PROCEDURE FOR DIFFUSION PROCESS STEP DIRECT COMPARISON EXPERIMENT

1. Obtain sufficient strips of web for two processing runs (48 strips).

2. Within these 48 strips, choose pairs of strips from the same web crystal.

3. Separate these 48 strips into two separate processing runs of 24 web strips each - each run containing one of the pairs chosen in Step 1.

4. Process one 24 strip run through the baseline gaseous diffusion process - the other 24 strip run through the liquid SiO_2-liquid boron process.

5. Finish processing all strips through remainder of Westinghouse baseline process.

TABLE 5

LIQUID SiO_2-LIQUID BORON VS BASELINE GASEOUS BBr_3 PROCESS

- Overall Runs

1. BBr_3 Baseline Process

	Experiment #1	Experiment #2	Experiment #3
No. of Cells	20	12	20
Average Efficiency	12.01%	12.55%	13.20%
Maximum Efficiency	14.33%	14.43%	14.03%
Minimum Efficiency	10.77%	11.02%	12.09%

2. Liquid Process

	Experiment #1	Experiment #2	Experiment #3
No. of Cells	16	18	8
Average Efficiency	12.68%	12.30%	13.60%
Maximum Efficiency	14.44%	13.0 %	14.69%
Minimum Efficiency	11.37%	11.33%	12.90%

3. Direct Comparison of Cells from the Same Web Crystal or Furnace Run

	Web Crystal No.	Avg. Efficiency Liq. Boron	Avg. Efficiency BBr_3
Pair #1	7.124-8.2	12.37 ±.07%	
	7.124-8.3		12.1 ±0.35%
Pair #2	6.138-7.2	12.5%	
	6.138-7.3		11.51 ±.38%
Pair #3	6.134-12.7	12.08 ±.32%	
	6.134-12.6		12.09 ±.05%
Pair #4	6.134-7.4	12.57 ±0.17%	
	6.134-8.5		12.80 ±0.34%
Pair #5	1.150-16.2	12.65 ±.25%	
	1.150-17.2		13.48 ±0.57%
Pair #6	4.112-8.3	13.13 ±.03%	
	4.112-5.2		13.66 ±0.15%

TABLE 6

PROCEDURE FOR DIRECT COMPARISON OF LIQUID MASK AND LIQUID BORON VS BBr_3 BASELINE DIFFUSION PROCESSES

1. Obtain sufficient strips of web for two processing runs (48 strips).

2. Within these 48 strips, choose pairs of strips from the same web crystal.

3. Separate these 48 strips into two separate processing runs of 24 web strips each - each run containing one of the pairs chosen in Step 1.

4. Use liquid* SiO_2 mask on sun side of all 48 strips.

5. Process one 24 strip run through the baseline gaseous diffusion process - the other 24 strip run through the liquid* boron process.

6. Finish processing all strips through remainder of the Westinghouse baseline process.

*For these experiments, Filmtronics solutions were used.

TABLE 7

LIQUID SiO_2-LIQUID BORON VS LIQUID SiO_2-BASELINE GASEOUS BBr_3 PROCESS

*1. Liquid Process

No. of Cells	37
Average Efficiency	12.10%
Maximum Efficiency	13.82%
Minimum Efficiency	10.86%

*2. BBr_3 Process

No. of Cells	31
Average Efficiency	11.30%
Maximum Efficiency	12.55%
Minimum Efficiency	10.20%

3. Direct Comparison of Cells from Same Web Crystal

	Average Efficiency	
Crystal	Liquid Boron	BBr_3
Pair #1	11.7%	11.0%
Pair #2	11.8%	11.4%
Pair #3	12.0%	12.1%

*The results from Items 1 and 2 should not be directly compared, since material variations as well as process variations are involved.

TABLE 8

PROCESS SEQUENCE FOR FABRICATION OF SOLAR CELLS USING LIQUID BORON AND LIQUID DIFFUSION MASKS

1. Raw web cleaning (including the hot H_2SO_4 treatment).
2. Pre-diffusion cleaning (standard chelating).
3. Paint on liquid SiO_2 on designated N^+ side using a sponge-squeegee.
4. Dry under heat lamp for 5 minutes (about 80°C).
5. Paint on liquid boron dopant on designated P^+ side using a sponge-squeegee.
6. Dry under heat lamp for 5 minutes (about 80°C).
7. Load strips in boat with SiO_2 side facing SiO_2 side and B side facing B side. Pre-bake in oven for 15 minutes at 200°C.
8. Place loaded boat in front end of diffusion furnace and bake strips for 5 minutes at approximately 300°C.
9. Move boat into furnace and diffuse for 40 minutes at 980°C. Slow cool furnace to 700°C at 3°C/minute.
10. Strip oxides in 2:1 H_2O:HF.
11. Repeat Step 2.
12. Paint on liquid SiO_2 on boron diffused side using a sponge-squeegee.
13. Repeat Step 4.
14. Load strips into boat with SiO_2 side facing SiO_2 side.
15. Place boat into front end of $POCl_3$ diffusion tube and bake strips for approximately 300°C.
16. Move boat into furnace and diffuse in gaseous $POCl_3$ for 20 minutes at 850°C (baseline conditions). Slow cool furnace to 700°C for 3°C/minute.
17. Strip oxides and complete baseline process.

batches were processed during this period. Of these batches, ten contained 1.6 cm x 9.4 cm cells while eleven contained 2.0 cm x 9.8 cm cells. Table 9 gives the efficiency data on the individual runs, and Table 10 gives data on the 21 runs with a breakdown as a function of cell size. Figures 1 and 2 show the efficiency distribution of the 1.6 x 9.4 cm and 2.0 x 9.8 cm cells respectively.

It is instructive to compare the results of the liquid boron/liquid SiO_2 runs (Tables 9 and 10, Figures 1 and 2) with the results of earlier baseline runs. Table 11 shows this data. In the period 3/15/82 - 6/11/82, there were a total of 3,195 cells (2.0 x 9.8 cm) tested with an average efficiency of 12.4%. This is in good agreement with liquid dopant verification runs. However, in the last thirty days of this three month period (5/15/82 - 6/11/82), there were 1,134 (2.0 x 9.8 cm) cells tested with an average efficiency of 12.8% and 465 (1.6 cm x 9.4 cm) cells tested with an average efficiency of 13.1%. The major difference between the cells produced in the verification runs and during the 5/1/82 - 6/11/82 period is that the efficiency distribution of cells in the latter period is skewed towards the higher efficiency end of the curve. Thus, the cells fabricated during the liquid dopant/liquid mask runs were equal to baseline runs made several months earlier but lower in efficiency than present baseline runs. This effect will be checked by following baseline runs made after the verification runs.

There was some improvement in throughput (production) of the liquid dopant/liquid mask cells as compared to the baseline process. This improvement has not been quantified since this first test run was mainly a learning experience. In the next series of runs, the production rate will be closely compared to the baseline production rate. To date these test/verification runs indicate that the liquid boron/liquid mask technique is suitable for the fabrication of high efficiency cells and modules. However, more runs and a detailed analysis of any increased throughput with the liquid process must be made to quantify the benefits of the process. Future work is planned in this area in the next period.

TABLE 9

LIQUID DOPANT/LIQUID MASK VERIFICATION RESULTS

Run #	# Cells	Avg. Efficiency	Max/Min. Efficiency
1*	32	11.9	14.2/10.7
2*	35	12.4	13.9/10.3
3	52	12.7	13.9/9.6
4	43	11.9	13.3/10.6
5	43	12.3	13.6/10.8
6	39	12.0	13.8/10.3
7	51	12.3	13.7/10.6
8*	47	12.2	14.2/10.0
9*	46	12.4	14.5/10.8
10	42	13.1	14.1/11.0
11*	56	13.1	14.7/11.8
12*	56	12.7	13.6/11.3
13	41	12.5	14.1/10.1
14*	48	13.0	14.2/11.8
15	23	12.1	13.4/10.0 (process problem)
16	43	11.0	12.6/8.7 (process problem)
17*	39	12.6	13.9/11.0
18	47	13.6	14.9/12.2
19	36	12.7	14.6/10.9
20*	51	12.5	14.5/11.3
21*	48	12.5	14.4/10.8

*1.6 x 9.4 cm cells (all other cells 2.0 x 9.8 cm)

TABLE 10

OVERALL DATA FROM LIQUID DOPANT/LIQUID MASK VERIFICATION RUNS

No. of Runs - 21

No. of Cells Tested - 918

Average Efficiency - 12.5 ±0.8%

Overall Yield: $\left(\frac{\text{Cells Tested}}{\text{Total Possible \# of Cells}} \times 100\right) = 61\%$

CELL PARAMETERS MEASURED FOR TWO DISCRETE CELL SIZES

			Average Values		
Cell Size (cm x cm)	# Runs	# Cells	V_{oc} (V)	J_{sc} $\left(\frac{mA}{cm^2}\right)$	Efficiency (%)
1.6 x 9.4	10	437	0.534 ±0.008	29.9 ±0.8	12.6 ±0.8
2.0 x 9.8	11	481	0.534 ±0.007	29.4 ±1.0	12.4 ±0.9

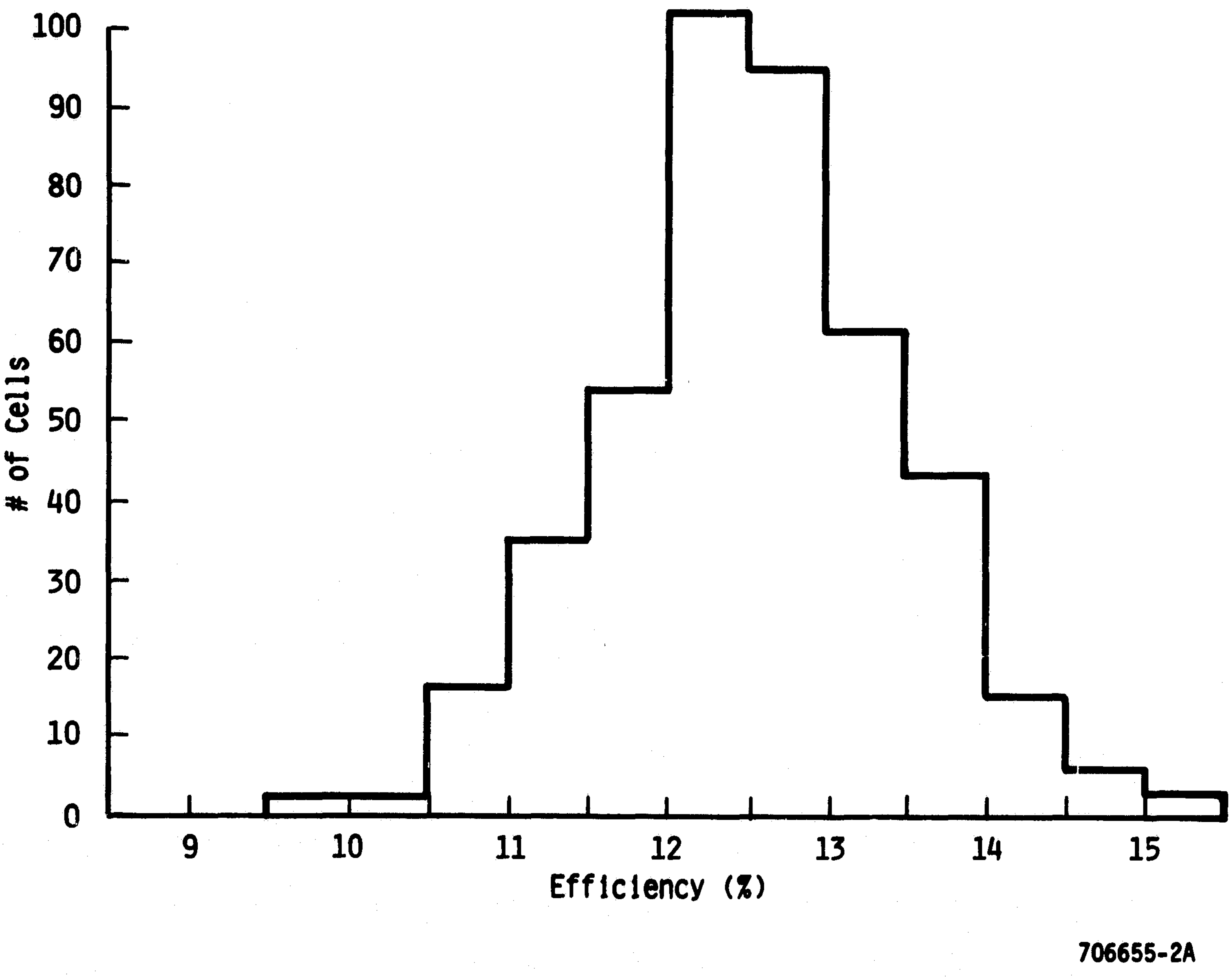

Figure 1. Efficiency Histogram of 1.6 cm x 9.4 cm Cells Fabricated in Liquid Boron/Liquid SiO_2 Verification Runs

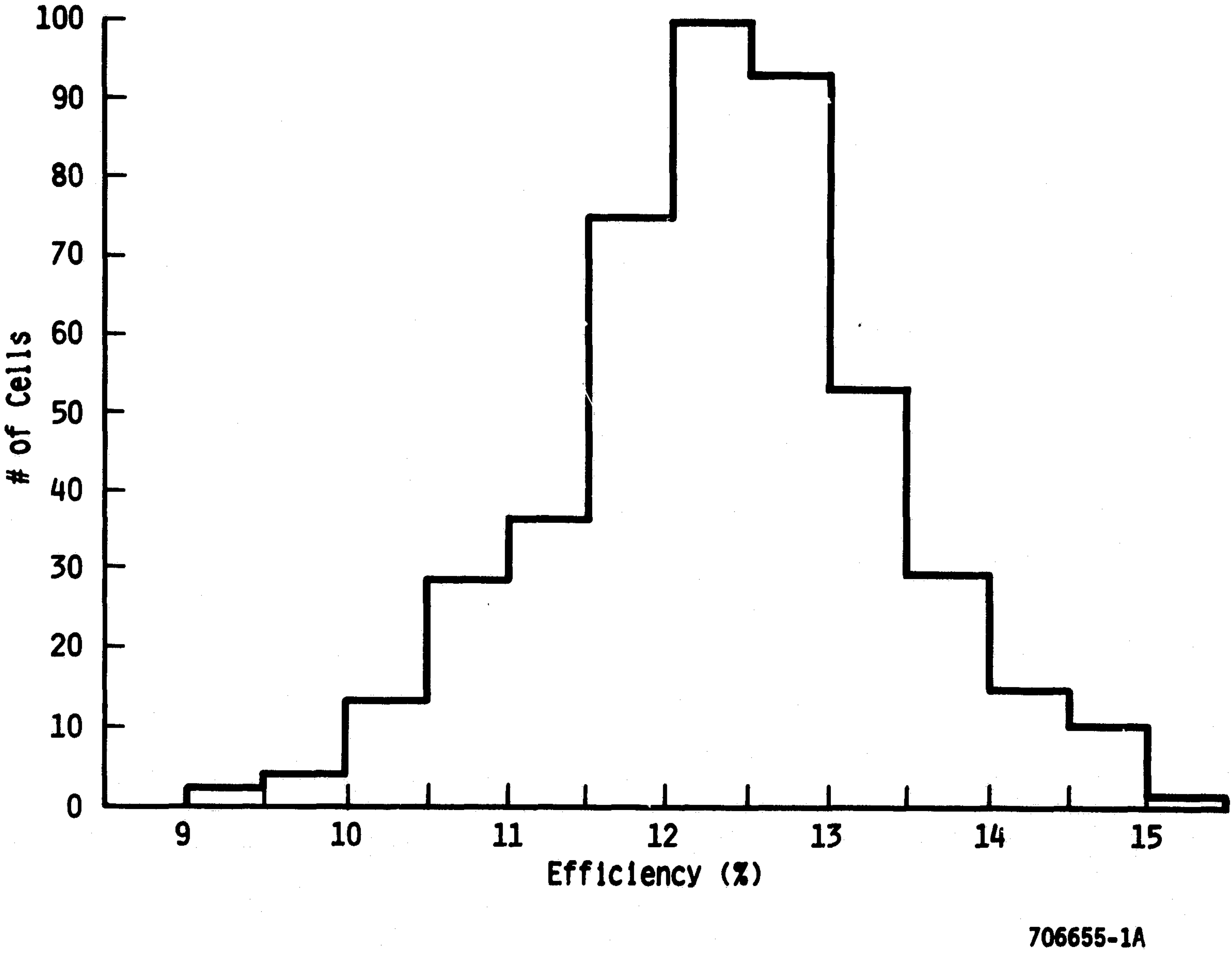

Figure 2. Efficiency Histogram of 2.0 cm x 9.8 cm Cells Fabricated in Liquid Boron/Liquid SiO_2 Verification Runs

TABLE 11

COMPARISON OF LIQUID BORON/LIQUID MASK VERIFICATION RUNS WITH BASELINE GASEOUS DIFFUSION RUNS

	Baseline Processing						Liquid Boron/ Liquid Mask	
Cell Size (cm x cm)	Inclusive Dates Cells Tested	# Cells	Avg. Eff. (%)	Inclusive Dates Cells Tested	# Cells	Avg. Eff. (%)	# Cells	Avg. Eff. (%)
2.0 x 9.8	3/15/82 - 5/11/82	3195	12.4	5/15/82 - 6/11/82	1134	12.8	481	12.4
1.6 x 9.4				5/15/82 - 6/11/82	465	13.1	437	12.6

D. Dark IV Measurements

Two cells, processed as in Table 6, were sent to Westinghouse R&D Center for dark IV measurements. Dark IV data were taken to determine any differences in the junction structure of the BBr_3 diffused and liquid boron diffused samples.

The dark IV curve for a solar cells can be expressed as:

$$J(V) = J_{01}\, e^{V/V_T} + J_{02}\, e^{V/nV_T}$$

where $V_T = \frac{kT}{q}$. k is the Boltzman constant, T is the absolute temperature, q is the electron charge, V is the cell voltage, and n is the diode factor.

The J_{01} term arises from current flow by carrier diffusion through the bulk. The J_{02} term describes current flow by recombination in the junction depletion region. The components (J_{01}, J_{02}) of the total current are sketched in Figure 3. Significant increases in the junction (J_{02}) current indicate junction degradation due to improper diffusion, impurity segregation, etc., which are noted by a lowered shunt resistance. Shifts in the bulk current (J_{01}) indicate bulk lifetime changes due to improper diffusion or bulk impurities.

It is important to note that the solar cell parameters of V_{oc}, I_{sc}, and efficiency can be affected by independent changes in the J_{01} and J_{02} currents. Therefore, this dark IV technique can be used as a diagnostic tool to study solar cell structure, material and processing quality.

Data on the two cells is summarized in Table 12. The very low values of J_{02} indicate high quality junctions, and the bulk lifetimes are close to that measured for good quality float-zone material.

E. Evaluation of Alternate Vendors' Liquid Solutions

In order to evaluate other vendors' liquid dopant solutions, a visit was made to Emulsitone, Inc., and Allied Chemical in New Jersey. During this period, a contact was also made with Diffusion Technology regarding their dopant solutions. An experiment was set up with these companies where Westinghouse will supply silicon web pieces, and the vendors will diffuse P^+ layers using their

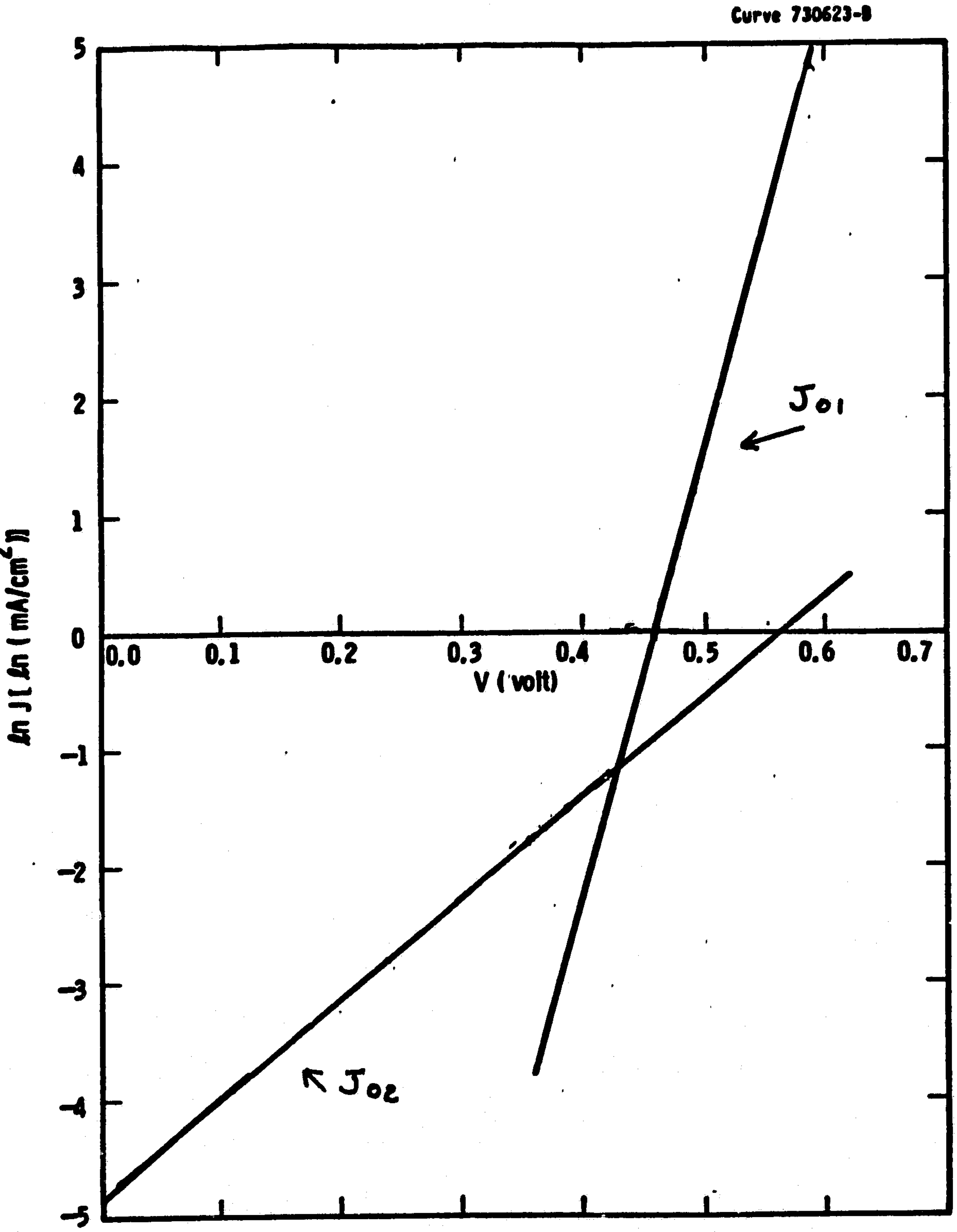

Figure 3. Generalize Dark IV Curve Segments for Bulk and Junction Currents of Solar Cells

TABLE 12

DARK I-V MEASUREMENTS

Cell ID	Cell Area cm^2	T Bulk µsec	J_{sc} ma/cm^2	V_{oc} Volts	Fill Factor	η %	R_S Series Resistance Ω-cm	R_{SH} Shunt Resistance kΩ-cm^2	J_{02} A/cm^2	Remarks
2102-15C	19.6	434	33.8	0.578	0.798	15.6	0.31	68	3.2×10^{-7}	Liq.Boron/$POCl_3$ Process
2090-36C	19.6	339	32.5	0.578	0.802	15.1	0.44	31	6.2×10^{-8}	Std B(BBr_3)/$POCL_3$ Process

(The bulk lifetime calculated from the dark I-V measurements cannot be directly compared to the OCD lifetime. It is, however, a good relative measure of cell quality.)

liquid boron dopants. These pieces will then be returned to Westinghouse AESD for gaseous $POCl_3$ diffusion and fabricated into solar cells.

Five strips 13 cm long were received from Emulsitone where a P^+ layer had been diffused using the Borofilm 100* solutionand Silicafilm* as a liquid diffusion mask. These strips were diffused at Emulsitone at 960°C for 45 minutes in 95% N_2, 5% O_2 ambient. The sheet resistance on these strips was 30-40 Ω/□ (Westinghouse specification), but there were blue stains on the P^+ side. These strips were then subjected to the gaseous $POCl_3$ diffusion process and fabricated through the standard Westinghouse baseline process as solar ĉells. Performance characteristics for three cells produced from these strips are three cells are given below:

Cell No.	V_{oc} (volts)	I_{sc} (ma)	FF	Area (cm^2)	η (%)
75A	0.573	469	0.78	15.04	13.9
91A	0.544	444	0.77	15.04	12.3
92A	0.563	465	0.77	15.04	13.4

These initial results look quite encouraging, and further experiments are planned in this area. These cells were sent to the Westinghouse R&D Center for dark IV measurements to determine the junction quality. Emulsitone will attempt to diffuse the N^+ junction using their N-250 phosphorus solution and return the strips to Westinghouse for solar cell fabrication to evaluate a total liquid process. The results of the dark IV measurements made on these three cells are shown in Table 12. The low values of J_{02} indicate good quality junctions, and the bulk lifetimes are quite acceptable. Further evaluations are planned for the next reporting period.

No results have yet been received on web strips sent to Allied Chemical. However, a run has been initiated using BX-10 liquid boron and UDG liquid SiO_2

*Trade name - Emulsitone Corporation

solution supplied by Allied Chemical. Detailed results will be reported in the next quarterly report. Web strips have been sent to Diffusion Technology for their liquid dopant/liquid SiO_2 studies. Samples have been requested to evaluate their liquid dopant solution.

Three web strips with a liquid P^+P back and a liquid N-250 phosphorus diffused N^+P junction were received from Emulsitone. The sheet resistivity on these strips was 40 Ω/□ which is about 20 Ω/□ lower than the Westinghouse specifications for $POCl_3$ diffusion. The sun surface was fairly badly stained, and only two cells could be fabricated from these strips. The data on these two cells is given below:

Cell No.	Cell Area (cm^2)	V_{oc} (volts)	J_{sc} (ma/cm^2)	FF	η%
60A	15.04	0.544	28.1	0.76	11.6
91A	15.04	0.534	26.3	0.73	10.3

The short circuit current density on these cells is significantly lower than cells fabricated using $POCl_3$ diffusions. The surface stains after diffusion and lower sheet resistance explains the lower J_{sc}. This confirms the hypothesis that unless liquid phosphorus can be applied uniformly using a meniscus coater, it is not feasible to fabricate high efficiency solar cells consistently using all liquid diffused junctions.

IV. ACTIVITIES PLANNED FOR NEXT QUARTERLY PERIOD

The following activities are planned for the next quarterly reporting period covering September, October, November 1982, time span.

1. Collect and analyze data on recent baseline runs.

2. Start another period of extended liquid boron/liquid SiO_2 runs to build up a data base.

3. Continue study of Emulsitone solutions.

4. Continue study of Allied Chemical solutions.

5. Investigate Diffusion Technology liquid dopant solutions.

V. PROGRAM DOCUMENTATION

All programmatic documentation specified in the Westinghouse Process Research of Non-CZ Silicon Material MEPSDU contract has been submitted in accordance with schedular requirements. A list of the programmatic documentation and submittal dates is compiled in Table 13.

TABLE 13

PROGRAM DOCUMENTATION SUBMITTAL STATUS

Item	Submittal Date
1. Monthly Technical Reports	
A. March 1982	April 1, 1982
B. April 1982	May 3, 1982
C. May 1982	June 3, 1982
D. June 1982	July 8, 1982
E. July 1982	August 2, 1982
F. August 1982	September 7, 1982
2. Financial Management Reports	
A. March 1982	April 6, 1982
B. April 1982	May 19, 1982
C. May 1982	June 14, 1982
D. June 1982	July 16, 1982
E. July 1982	August 16, 1982
F. August 1982	September 14, 1982
3. Program Plan, Cost Estimates, & WBS	
A. Original	March 12, 1982
B. Revision	May 26, 1982
4. MEPSDU Summary Report	
A. Draft	June 3, 1982
B. Final	July 26, 1982